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A Tool for Holistic Assessment of Digitalization Capabilities in Manufacturing SMEs

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Abstract

In a constantly evolving global market, manufacturing companies need to be flexible and adaptive to survive. Digital twins of production systems have been proposed as one part of the solution, however this comes with multiple challenges. Manufacturing SMEs have limited resources and need to direct their efforts in this area wisely. This paper presents a tool for holistic assessment of an SME manufacturer's level of digitalization, in order to visualize current gaps and guide digitalization efforts over a production system's life cycle. The tool was empirically developed together with Manufacturing SMEs and has strengthened their digitalization awareness and capabilities.

Keywords: Industry 4.0; smart manufacturing; digitalization; digitalization capabilities; SME

1. Introduction

With a constantly evolving industry there is a need for flexible and adaptive production systems in order to stay competitive on the market [1, 2]. This can be achieved with the implementation of Industry 4.0 and the ongoing digitalization of industry [3]. In the implementation of these modern production systems the focus should be on a holistic approach towards digitalization [2]. In order to do so, companies need to focus on how to best implement and carry out their own digital transformation.

Major challenges with the implementation of the necessary changes are for example missing the bigger picture and emphasizing technical solutions [4, 5] and difficulties with how to connect things within the company [6]. Failing to deal properly with these challenges can lead to a digital transformation that slows down and takes longer than expected, leading to poor efficiency and economic losses [7]. The challenges can also hinder future transformation due to the creation of an unbalanced production system with many different levels of digitalization internally [5].

Successful adaptions to a digitalized industry are achieved in stages where the company need to make long term plans based on current data in each stage [8, 9], which can be supported in a good way by collecting necessary data using mapping tools and methods. To collect this data successfully it's preferable to have reliable and consistent measuring points [10]. This can be achieved by mapping weak points where new technology is beneficial to the production and simultaneously identifying which parts of the company are using outdated technology. As the mapping is then based on information gathered on how the company operates today, the implementation of digitalization is more likely to have a holistic approach. The purpose of this paper is to present a tool which can be used to support such a stage-wise mapping and implementation, to achieve a holistic digitalization transformation strategy in manufacturing companies. Literature on available tools and methods for the implementation of digitalization showed that a variety of methods for measuring digital maturity and readiness exist, but there were no tools for planning and implementation. These kinds of tools could be beneficial for both the industry and the field of research [4, 9].

In order to introduce this tool, the paper is organized in six sections as follows. Section 2 covers other methods for mea-

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suring digital maturity and readiness. Section 3 presents the methodology used to create and verify the tool. This is followed by Section 4 where the components of the tool are presented and described. Section 5 contains guidelines on how to apply the tool and analyze its result along with summarized results of case studies. Section 6 concludes the article with some notes about the application of the tool, what it can offer and recommendations for future development.

2. Other methods and tools

Getting companies in shape for the digital future can be viewed as a three-step process [11], starting with analyzing and identifying coming changes in technology and management systems, continuing with analyzing the digital maturity of a company in order to determine gaps and under-developed sections, followed by using this information to create a road map for the implementation and digital transformation. The first step of analyzing what the future holds, what coming technologies to invest in and work with, is widely carried out by researchers and others in the field. When it comes to the road to implementation there are a variety of methods and tools available that focus on companies maturity and digital readiness measures [12], laying focus on the first two steps in order to map and capture a company's starting point in their transformation [9]. The readiness models can be used before the company starts the transformation to capture the current state [11]. Methods and tools studied in this paper supporting the implementation of digitalization are summarized in Table 1.

Table 1. Maturity models

Method	Description
eBlomlådan [13]	A tool that measures the level of digitalization in Swedish municipalities. A individual questionnaire is sent out to participants measuring administrative digitalization. The goal with the study is to raise awareness of how to improve their digital service.
Industrie 4.0 maturity index [4]	German study that developed a model for measuring digital maturity. It is a six-stage maturity model, to help companies plan Industrie 4.0 development and transform into an agile company.
Impuls industrie 4.0 readiness [14]	A readiness model to classify companies in three different types of digital readiness levels. It is done by answering questions under six dimensions of Industrie 4.0. The survey is a foundation for an online self-assessment comparison tool where companies can perform self-checks of Industrie 4.0 readiness in these six dimensions.
Maturity model for assessing Industrie 4.0 readiness [15]	Method developed to shed light on organizational aspects not only technology focus, common for other methods. The method defines nine dimensions of digitalization with 62 items for assessing Industrie 4.0 maturity.

Other findings include an extensive Swedish literature study which compiled different aspects of digital transformation regarding different manufacturing industries and their transformation process [7]. It gave information about state-of-the art regarding technical aspects of digitalization such as simulation, big data and what is necessary parts for being classified as a digital company [7]. The study also described the need for a reality-based tool tested on real companies to help companies plan their digital transformation by finding and exploiting areas of digital weakness [7].

3. Methodology

The development of the tool is based on different research methodologies and research approaches in order to create a tool that reflects how the industry operates today while showcasing what is achievable by using state-of-the-art digital information systems and technical solutions. The tool was developed in stages and tested in different ways to verify the concept and the tools applicability while simultaneously making it relevant for industry. These stages included tests on fictitious companies, real companies and consulting with experts of the field. The development process was divided into a tool generating part, building the tool structure, and development part where the tool was refined and tested. Figure 1 present a summary of all steps in the development process timeline.

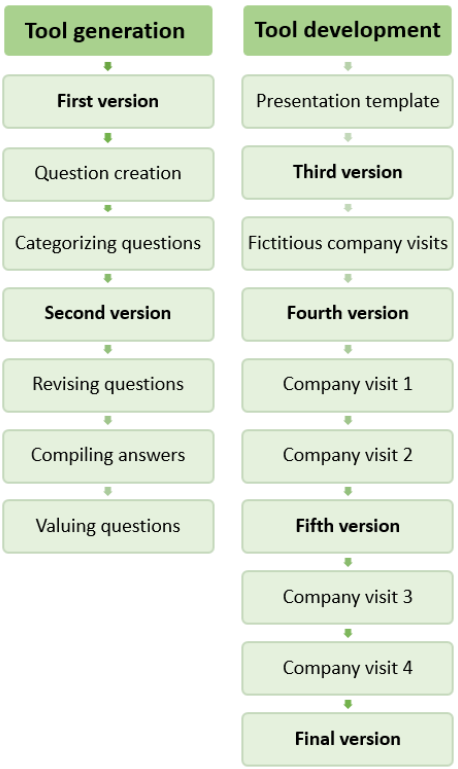

Fig. 1. Timeline of the development process

3.1. Data collection

The data for the development of the method were gathered with the research methodology Grounded Theory. This approach of collecting data is based on evolving a new theory, rather than improving an already existing one [16], by

collecting data from empirical studies. Data was collected in semi-structured interviews and guided tours during seven different companies visits at Swedish manufacturing companies. The companies were analyzed in order to generate an overview of the current digital state and work methods present. The companies had different industrial connections as suppliers of automation solutions or classical manufacturing companies of different sizes, however all companies fall under the classification small and medium-sized enterprises (SMEs).

A literature study was carried out in addition to the data gathering at the SMEs, including both Swedish and English publications, covering possibilities and opportunities with high digitalization technology and which areas in the transformation process is most critical in order to support both the tool development process and the tool generation process. In addition, a literature study on other methods was performed, in order to pinpoint existing gaps in the implementation and planning phases of digital transformation methods.

3.2. Verification, validation and case studies

The studied methods and tools helped with constructing a framework for the developing tool. This framework included how the tool presented in this paper should be structured in best possible way and how it should be presented. These observations lead to choosing a structured interview as the way to use and analyze a company, to avoid biased self-reporting [13].

As discussed in chapter 2 there is a lack of tools for gathering information on what needs to be done to take the company to their next digital step in a holistic way. A tool based on reality that is fast to use and can be used continually throughout the transformation process in order to ensure that the change happens in the best possible way needs to be well tested in reality [7, 12].

To achieve this the verification on real companies was an important step in constructing the tools and its features. By putting the tool in the right context, data could be collected on what parts worked and what needed to be improved. The companies used for the verification and validation process were a mix of previously studied during the data collection and new ones with different business alignments, to get input form as many angles as possible. Table 2 categories the four companies used in the case studies.

Table 2. Overview of studied companies

Company	SMF	Industry	Manufacturing company
Company 1	X		X
Company 2	X		
Company 3		X	X
Company 4	X	X	

4. Structure of the tool

The tools consist of three different components, a tree structure (Figure 2), a questionnaire (Figure 3) and a stair (Figure 4) described in coming sections [17].

4.1. Tree structure and questionnaire

The tree structure is an illustration of the categories that are investigated to determine a company's level of digitalization. It consists of two main categories, the digital twin and the information flow of a company. These areas are further divided into eight subcategories, see Figure 2, to categorize the different areas that impact a digital twin or the information flow. All categories are valued and weighted against each other since different areas can have higher or lower impact on a company's digital level [7]. This will also provide a more dynamic and realistic result on critical areas where much can be gained from increasing the company's digital level. An example of this is that the category Internal information flow, which is valued higher then the External information flow, since a company's digital level should not be as affected by their customer or suppliers digital operating level.

These categories contain a total of 37 question to determine level of digitalization in each category. Each question has five answers representing lowest to highest available digital level of the question. Each question as same as the categories are valued against each other to get a dynamic result and have the key parts of becoming digitalized weighing heavier. An example of questions from different categories can be viewed in Table 3.

The questionnaire was made to support the mathematics of having different weighted questions and to keep track of all questions, categories and to make it user friendly (Figure 3). Some of the features in this questionnaire includes being able to choose not to answer the question if it feels irrelevant, make a comment about the question for further analysis or get an insight on the weight of each answer of the total digitalization level at the company.

When all the relevant questions have been answered the digitalization level in percentage for every category will appear in a summarizing table in the questionnaire and also under each category in the tree structure, Figure 2.

4.2. Digitalization stair

To analyze the result and put the percentage in perspective the stair is used. It shows which level of digitalization the company have by converting the calculated percentage from the questionnaire to a level of digitalization (Figure 4). The level descriptions are formulated based on the information from the company visits and case studies. The levels correlate to the level of digitalization for each different answer, one to five. An example is using paper drawings when planning layout changes, which is the lowest digital level and there for correlated to level 1 where using digital 3D models is highest digital level today. The explanations of each level are made so that companies can see where they are in their transformation and what to aim for

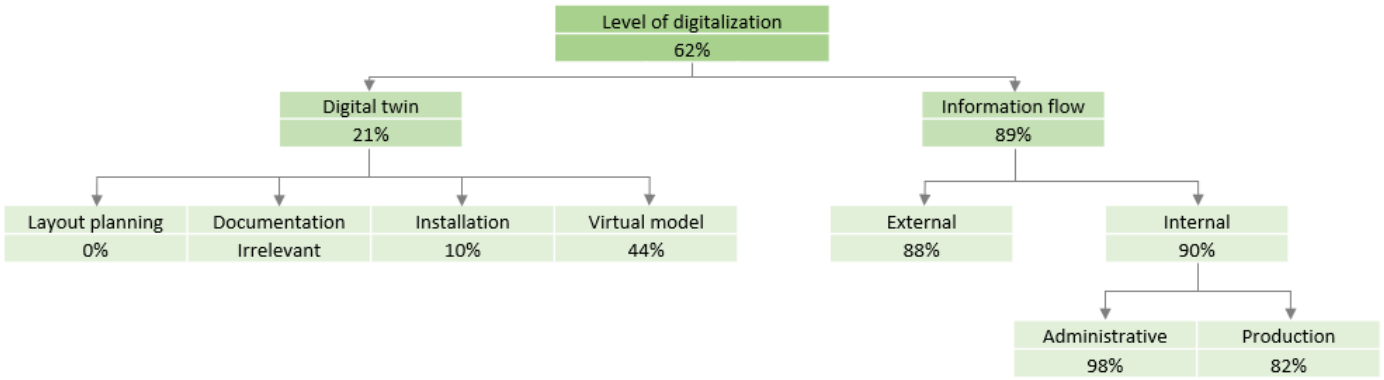

Fig. 2. The hierarchical tree structure of the tool, with all categories displayed. The percentages is an example on how the result is displayed ones the questionnaire is filled out.

Virtual model	6,25	1		2		3		4		5				
How is your facility documented?	3,00		0		0		0		0	5	5	5,00	18,75	0,94
How is your virtual model created?	1,00		0		0		0	4	4		0	4,00	6,25	0,25
To what can you use your virtual model?	2,00		0		0	3	3		0		0	3,00	12,50	0,38

Fig. 3. The design of the questionnaire, displaying three questions from the category Virtual model. The questions weight in percentages are displayed in the column next to last and total impact with regard answer alternative furthest right. The complete questionnaire can be found in reference [17].

Table 3. Example of questions from different categories, all questions be found in reference [17]. The questions are directly translated from original language.

Question	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Which visual tools is used when planning layout changes?	Paper drawings, 2D	Digital drawing, 2D	Digital model, not editable, 3D	Digital model, editable, 3D	Digital model, point cloud, 3D
To what extent is the master layout updated after changes?	Does not have a master layout	Do not update	Set interval	Before or after major changes	Before or after any changes
Which measurement equipment is used in the installation stage to determine the location of the layout change?	Analog measuring tools/instrument	Digital offline tools/instrument	Digital online tools/instrument	Digital tools, temporary reference points	Digital tools, fixed reference points
How is your facility documented?	Not documented	Paper drawings, 2D	Digital drawing, 2D	Digital model, 3D	Digital model, point cloud, 3D
Do you simulate the layout change before installation?	Do not simulate	No	No, but used for visualization	Yes, simulated	Yes, simulated and adjusted if needed
How can you share files with your customers?	Analog transfer	Physical file transfer	Digital file transfer	Cloud services, with preview	Cloud services with editing option
How are files shared internally?	Analog transfer	Physical file transfer	Digital file transfer	Cloud services, with preview	Cloud services with editing option
How is information generally transferred in the company?	Analog transfer	Physical file transfer	Digital file transfer	Cloud services, with preview	Cloud services with editing option
What method is used to collect production data?	Not collect	Guess or estimate	Manual measurement	Automatic measurement, single variables	Automatic measurement, multiple variable
How is information collected from measurement equipment?	Not collected	Physical file transfer	Digital file, manual handling	Digital file, transfer manual upload	Digital file, transfer automatic upload
How is the production information/data stored?	Physical storage, analog	Physical storage, digital	Digital storage, internal network	Digital storage, cloud services with preview	Digital storage, cloud services with editing option

in order to become more digital. Each level can be describes as followed.

Level 1: Companies in this category generally only use obsolete technology. None of the opportunities that exist with the technology shift are utilized and there is also no incentive to enter the next technology shift as this is not a goal for the company.

Level 2: Companies in this category generally use a mix of outdated and newer technology. Few of the opportunities that exist with the technology shift are utilized, but there are incentives to enter the next technology shift, even if active steps or plans are few.

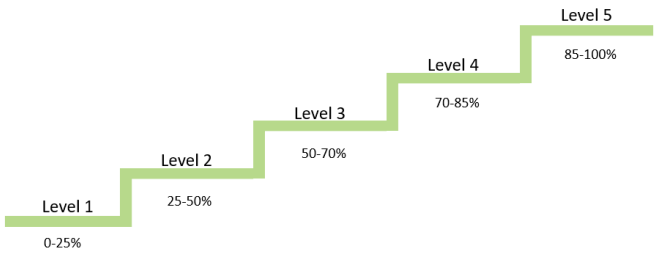

Fig. 4. Digitization stair displaying the different levels of digitalization

Level 3: Companies in this category generally use a mix of outdated and newer technologies where the majority are newer. Some of the opportunities that exist with the technology shift are being exploited and the transformation is in the planning state but only few active steps are taken to being more digitized.
Level 4: Companies in this category generally use newer technologies where there are few elements of outdated technology. Many of the opportunities that exist with the technology shift are being exploited and the business is well into the next technology shift as active steps are taken in to being more digitized.
Level 5: Companies in this category generally use only new technologies. Most of the opportunities that exist with the technology shift are being exploited and the business is at the forefront of the next technology shift as plans are set up an actively carried out.

5. Application and case study

5.1. Instructions for application

It's recommended to apply the tool with a structured interview. The interview is preferably carried out by an external interviewer who presents each question to a representative of the company. They can with this structure objectively discuss how the company works today and together choose the best describing answer to each question. If two answers seem right, it is recommended to choose the one most widely used or, preferably, the worse one, to have something to work towards. The interviewer can also clarify questions and note important aspects that can come up in the discussion for future use.

When every question is either answer or deemed as irrelevant a table will be displayed for the interviewer containing each categories level of digitization, see Figure 2. The level of digitization is displayed in percentage to display an easy and quick overview of the digitization status at the company. Each category's percentage is displayed to see its effect on the overall result and immediately have the ability to bring a category up and analyze which questions and answers affect the overall result.

The questionnaire, along with the table, gives the interviewer a good overview of where the company lack important milestones and where they should focus their transformation. The representative and the interviewer can then discuss each category individually and how they affect the final level of digitalization, which also will be illustrated at the top of the tree structure. There is also the possibility to view each question's individual impact on the total result, see Figure 3.

Finally, the percentage can be converted and fitted into a level, a level of digitization, which are illustrated in a stair Figure 4. The stair is described in chapter 4 with the five different steps gives a pedagogic illustration about where the company are today and a description what is generally needed to reach the next step of digitalization. The stair and the answers also work as an incentive for companies to show tends and to thrive for the top and achieve the best answer.

5.2. Case study results

The case studies made to hone and develop the tools content included manufacturing companies and office-based companies in order to make the tool applicable on more branches or sectors, see Table 2 for categorization of case study companies. These case studies showed that most of the time the main reason for not doing a digital transformation where the difficulty to find balance between efficiency and digitalization or the fear of change. Many of the companies already had quite effective ways of handling a problem with less digital solutions, where changing to a more digital ones would not necessary be a better solution and could potentially lead to loss in efficiency short-term. But when discussing it in a long-term perspective they all agreed that the digital one would often become a better solution and that you need elaborate whether or not is worth it.

The evaluation needs to take the goal of the transformation in to perspective. The different solutions to each question could be analyzed to which could fit the company's profile and match the other categories levels best. The smaller companies or ones from other sectors then manufacturing industries had naturally higher digital level in their information flow while the bigger companies could see the benefits in investing in advanced digital solutions in a way that smaller could.

This is where a balance between digitalization and effectiveness is needed, moving away from the exiting new technology and providing the opportunity to sit down and analyze strengths and weaknesses with the company before taking actions, fitting the right digital level to a company's need. Avoiding the uneven level of digitalization that can be caused by sporadic implementing new technologies without a holistic view and plan as discussed in chapter 1.

The questionnaire was always carried out by an external interviewer for the purpose of direct feedback during the development process, but also to offer an external analysis of the state of the company.

The main difference from our tool and the other ones mentioned is this development with real companies. This step of the generation ensured relevance and user friendliness of the tool.

The case studies had great effect on changes made during the development process. During the interviews, representatives from the companies saw the potential to have a quick (cheap) tool for annual checkups or checking in on how changes and improvement plans are coming along. Making notes

about which answer is best suited at the time makes for easy feedback when moving forward. This will enable the company to stop being in the planning and maturity phase and move on to having a tool for developing an action plan and finding weaknesses within the company, as well as with the answers given display a goal state for each area to work towards.

6. Conclusion

With this tool modern technology can be implemented in a holistic way to create flexible a production system that doesn't compromise the effectiveness of the company. This is achieved by measuring the company's level of digitalization within different aspects such as the company's information flow and technology use with focus on digital twins. The tool is based on a questionnaire that collects data which creates an analyzable overview that is able to guide companies in their digital transformation.

The tool is developed based on empiric data from SME companies in Sweden and an extensive literature study of methods and tools concerning digitalization implementation efforts and industry 4.0. This empirical data about how companies work is part of what makes the tools applicable and useful. Also, by continuously verifying the tool during the development process in an iterative manner by introducing new companies with varying business alignments both sufficient depth and scope is ensured.

The tool aims to reflect the studied companies work methodology and strategy rather than specific technical solutions. This is a key part of implementing holistic digitalization; to support implementation of change in manufacturing methodology and strategy, and in the long term incorporating it into their business strategy. The tool can be used for mapping and visualizing a company's digital habits and pinpoint the area of their business in most need of improvements, while simultaneously collecting data usable for planning the transformation towards increasing their level of digitalization.

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